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AN EXAMINATION OF SELECTED DIGITAL FLIGHTPATH GENERATORS

Final Report

D. K. Sanders
N. L. Papke

November 1977

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Prepared for

THE JOINT LOGISTICS COMMANDERS
JOINT TECHNICAL COORDINATING GROUP
ON
AIRCRAFT SURVIVABILITY

FOREWORD

This report documents work accomplished from May 1974 to December 1975 by the Applied Sciences Department, NWSC, (Naval Weapons Support Center), Crane, IN. Work was performed under the cognizance of Mr. H. F. Campbell, Army Materials and Mechanics Research Center, Watertown, MA. Messrs. D. K. Sanders and N. L. Papke performed the work reported herein.

The work was sponsored by JTCG/AS as part of the 3-year TEAS (Test and Evaluation, Aircraft Survivability) program. The TEAS program was funded by DDR&E/ODDT&E. The effort was conducted by Methodology Standardization and Analysis Panel of the Survivability Assessment Subgroup, under TEAS element 5.1.7.2, *Baseline Assessments.*

This report is the product of a jointly conducted effort and presents four flightpath generation computer models. Special acknowledgement is given to Mr. Floyd Chinn, Aeronautical Systems Division (FAIR PASS); Capt. George Orr, formerly of the Air Force Armament Laboratory (FLYGEN); Lt. Col. Sam Baty, Studies and Analysis, USAF, (BLUE MAX); and Messrs. Don Merkley, Eustis Directorate, USAAMRDL, and Tom Wood, Bell Helicopter Company (MCEP).

NOTE

This technical report was prepared by the Survivability Assessment Subgroup of the Joint Technical Coordinating Group on Aircraft Survivability in the Joint Logistics Commanders organization. Because the Service's aircraft survivability development programs are dynamic and changing, the report represents the best data available to the subgroup at this time. It has been coordinated and approved at the JTCG subgroup level. The purpose of the report is to exchange data on all aircraft survivability programs, thereby promoting interservice awareness of the DoD aircraft survivability program under the cognizance of the Joint Logistics Commanders. By careful analysis of the data in the report, personnel with expertise in the aircraft survivability area should be better able to determine technical voids and areas of potential duplication or proliferation.

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This report describes the findings of an investigative analysis of four flightpath generation computer models. The four models (FAIR PASS, FLYGEN, BLUE MAX and MCEP) are commonly used in the aircraft survivability/vulnerability community. The first three are primarily fixed-wing models, while MCEP is exclusively a rotary-wing flightpath generator. All four models were acquired, installed, tested, and analyzed at NWSC (Naval Weapons Support Center), Crane, IN. Criteria such as capabilities, limitations, ease and economy of use, and compatibility with attrition models were considered in the evaluations.

NOMENCLATURE

Abbreviation/ Symbol	Definition
AA	Antiaircraft
BLUE MAX	Variable Airspeed Flightpath Generator Computer Program
deg	Degrees
deg/sec	Degrees per second
ft	Feet
ft/sec	Feet per second
FAIR PASS	Fighter Aircraft Penetration and Survivability Simulation
FLYGEN	Aircraft Flightpath Generator Computer Program
FORTRAN	Formula Translation (computer language)
g	Gravity
JTCG/AS	Joint Technical Coordinating Group/Aircraft Survivability
KN	Kilo-Newtons
m	Meters
m/sec	Meters per second
MCEP	Maneuver Criteria Evaluation Program
NWSC	Naval Weapons Support Center
P001	AA Artillery Simulation Computer Program - AFATL Program P001
rad	Radians
sec	Seconds
V/STOL	Vertical Short Take-off and Landing

CONTENTS

INTRODUCTION

Four flightpath generation computer models were acquired and installed by the NWSC (Naval Weapons Support Center), Crane, IN., to determine their relative suitability in attrition modeling. FAIR PASS, FLYGEN and BLUE MAX were utilized to generate flightpaths for the A-7E and F-4E fixed-wing aircraft used in these baseline survivability assessment studies. (Flightpaths for the A-7E and F-4E were constructed by the University of Dayton Research Institute and are described in a previous JTCG/AS report .) FAIR PASS was the first model acquired by NWSC. FLYGEN and BLUE MAX were acquired after a preliminary study [2,3] showed further attention was merited. FLYGEN was found to be the more general and versatile of the latter two models. A copy of MCEP, a rotary-wing flightpath generator, was installed to generate flight profiles to correspond with scenarios used in a Marine Corps survivability study of the CH-53E assault transport helicopter and in a survivability assessment of the AH-1G.

This report reflects interest in the models from a user's standpoint. Such features as ease and economy of use, efficiency, adaptability, and compatibility with attrition models are discussed, as well as an analysis of the mathematical and programming techniques used. Because the designs and intended uses of the four models are so dissimilar, no attempt was made to rank them. They are discussed in the chronological order of their acquistion by NWSC.

FAIR PASS

FAIR PASS (Fighter Aircraft Penetration and Survivability Simulation) is an AA (antiaircraft) attrition model developed by Air Force Studies and Analysis. The flightpath generator constitutes a major portion of the model as a result of extensive refinements[4] to make it more responsive to user inputs and to enable more stylized flightpaths to be created. A flightpath is synthesized by designating points in space that the aircraft endeavors to attain, and by designating a series of maneuvers to be used. The major maneuvers include: cruise, climb, descent, jinking, attack, and six hard maneuvers.

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[1] Applied Sciences Department. *Mission Scenarios for Survivability Assessment* by D. N. Montgomery and N. L. Papke, Naval Weapons Support Center, Crane, IN., October 1976. 136 pp. (JTCG/AS-75-S-003, publication CONFIDENTIAL.)

[2] Air Force Armament Laboratory. *Aircraft Flightpath Generator Computer Program* by Capt. G. Orr, Armament Systems Inc. Eglin, AFB, FL., AFAL, April 1976. 471 pp. (Publication UNCLASSIFIED.)

[3] Aeronautical Systems Division. *Variable Airspeed Flightpath Generator Computer Program (BLUE MAX)*, by Maj. O. Komarnitsky, Armament Systems, Inc. Wright-Patterson AFB, OH., ASD, October 1975. 153 pp. (Publication UNCLASSIFIED.)

[4] Naval Weapons Center. *FAIR PASS Computer Model;* Volume I, User Manual, by W. L. Goodson, D. P. Olsen, and C. B. McKinney, Air Force Studies and Analysis. China Lake, CA., NWC, May 1973. 91 pp. (Publication UNCLASSIFIED.)

The FAIR PASS model generates a flightpath which a specific aircraft is capable of flying. The generator is composed of the following three sections:

1. Aerodynamics. The aircraft and its responses to roll rates, *g*-rates, and thrust.
2. Logic. Compares the desired flight profile specified by input data with the aircraft's present position and velocity, to generate error signals.
3. Pilot feedback. Uses error signals as cues to develop roll rate, *g*-rate, and thrust outputs, which are fed back into the aerodynamics section to generate new aircraft position and velocity information for the next time increment. Response functions in the pilot feedback loop can be adjusted to approximate actual pilot responses.

INPUT DATA

Inputs consist of basic engineering data on the aircraft and its ordnance, and a desired flight profile. These data include lift, drag, thrust, and fuel consumption curves as well as aircraft and ordnance limitations. Coefficients for functions which describe pilot response also are included in this category. The input for a desired flight profile is an array of numbers describing the maneuver type and corresponding control data for each of up to 50 flightpath segments. Both types of data are stored in the program in the form of block data*, including data for a base case. To design a new flightpath, it is only necessary to input NAMELIST cards specifying those parameters which are being changed from the base case. Data contained on the NAMELIST cards override corresponding block data during the current run. At the conclusion of the run, block data are restored, leaving the base case intact until the next run. This allows construction of a fairly complex flightpath from a small number of data cards.

OUTPUT DATA

Outputs consist of all input parameters and a detailed history of the flightpath. The list of input parameters includes all the block data as modified by the NAMELIST input. Flightpath history output includes:

1. position, ft
2. components of acceleration, ft/sec^2
3. velocity, ft/sec
4. load factor, *g*
5. pitch, roll and heading angles, rad
6. angle of attack, rad
7. throttle control settings.

These data are printed for each one-half second of simulation time.

*Block data: A FORTRAN feature whereby a subprogram is used to initialize labeled COMMON.

FAIR PASS uses a conventional right-hand axis system for both the inertial and aircraft coordinate systems. The Z-axis of the aircraft is parallel to the Z-axis of the earth system. The X-Y plane is perpendicular to the Z-axis, and therefore parallel to the X-Y plane of the earth. The X-axis is positive forward and the Y-axis is positive out the left wing of the aircraft. The aircraft acceleration components are computed parallel to aircraft coordinate axes and then resolved into components with respect to the inertial or ground coordinate system. A positive pitch angle refers to nose upward. A positive roll angle means the right wing is down. The heading angle is zero for a heading parallel to the positive direction along the X-axis and increases positively in a counterclockwise direction.

An option is available to output flightpath parameters for input to the standard AA attrition model P001 [5] on an auxiliary output device (tape, disk, or punched card). All flightpath history is handled at one location in subroutine OUTFP, making this auxiliary output a simple programming change. For example, only 11 additional FORTRAN statements were required to do the necessary unit conversions and write out data compatible with P001. In this sense, the flightpath generator from FAIR PASS is readily adaptable to general use with other attrition models.

MANEUVER ROUTINES AND SUBROUTINES

In addition to a control routine and data handling subroutines, the program consists primarily of a group of maneuver subroutines. The four major ones are: CCD (climb, cruise, descent), AJINK (jinking path), ATTACK, and HARDM (hard maneuvers). The control routine checks the type of maneuver specified for a given leg, then transfers to the subroutine corresponding to that maneuver, where the flightpath history for that leg is calculated. Control returns to the control routine when one of several termination conditions is met.

For each maneuver subroutine except HARDM, the same mathematical philosophy is used. First, an aimpoint is computed. This aimpoint is a fixed or recomputed position in space that the aircraft must attain in the future to fulfill its goal. The next step is to develop the desired bank angle, *g*-loading, and throttle setting to attain the aimpoint. During this process, checks are made to insure that no aircraft parameter maximums or minimums are violated. The third step is to compute aircraft performance, i.e., its position in space, velocity and acceleration components, and so forth, at each point of the flightpath.

The mathematical techniques used throughout FAIR PASS involve empirical equations with six degrees of freedom. Any angular changes greater than 180 degrees are adjusted to be done in the direction of lesser change. Desired bank angle is computed as a function of horizontal and vertical *g*-loadings, which are estimated by two empirical equations and then corrected based on the maximum allowable total *g*-loading for that aircraft. Air density and speed of sound are calculated at operating altitude, and are then used to compute Mach number, dynamic pressure, and coefficient of lift. In order to use the empirical equations describing the aircraft thrust at various power settings, speeds, and altitudes, a critical Mach

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[5] Naval Weapons Center. *Antiaircraft Artillery Simulation Computer Program P001* Volume I, User Manual, by James Severson and Thomas McMurchie, Air Force Armament Laboratory, China Lake, CA., NWC, September 1973. 98 pp. (NWC TN-4565-16-73, Volume I, publication UNCLASSIFIED.)

number is defined. (Critical Mach number is that Mach number at which a break in engine thrust occurs.) Mach number coefficients in the thrust equations also are dependent on whether the aircraft engine is operating at afterburner or military power; the type of power used is an input variable. The maximum lift coefficient is computed as a function of Mach number, and is then used to calculate aircraft lift, normal load factor, angle of attack, and aerodynamic drag. Aircraft weight and mass are adjusted at each time increment by equations based on specific fuel consumption and the type of power being used. Resolving thrust, drag, and lift forces parallel to an axis and dividing by aircraft mass yields the aircraft acceleration along that axis. This acceleration is then assumed constant for a short time, enabling new aircraft position coordinates and velocity components to be obtained. The various angular orientations also are updated at each time increment.

Several runs may be required to build a flightpath to desired specifications. Frequently, output from the initial run will deviate significantly from the planned result after the first few legs. It then becomes necessary to note the terminating conditions of the last good leg, define the initial conditions of the next leg accordingly, rerun the program with that leg added, and so on until the flightpath is complete. Since an added segment may not behave as planned, several reruns may be needed.

CCD

CCD computes aircraft position, roll angle, velocity, and climb angle from initiation of the climb, cruise, or descent to the end of a previously defined leg. If the CCD leg is the first of the flightpath, the initial point and vector can be defined in such a way that the path will be straight. If it is not the first leg, and if the position and vector at the start of the leg are different than the desired initial conditions, the flightpath will be adjusted to capture the stated vector and terminal point. This is done by overcorrecting the vector and then recapturing the desired track by approaching it asymptotically from the other direction. Termination occurs when the following conditions are met: (1) the distance traveled along the CCD segment exceeds the specified segment length, and (2) the angle between the specified track and the vector from the current aircraft position to the designated initial point is less than 10 degrees. When aircraft position at the start of the leg is far different than planned, the leg might be much longer and in a different direction than specified to meet termination conditions. This type of error tends to be compounded in the segments which follow, and nearly always necessitates a rerun with adjustment of parameters to obtain desired results.

AJINK

In AJINK, the flightpath is computed for an aircraft performing a series of jinking maneuvers. The jinks used in this mode are planned evasive maneuvers which might be used in a target approach through a suspected defended area. The plane in which the aircraft is performing the jinking can be tilted upward or downward and to the right or left with respect to the ground plane. Inputs include a desired constant load factor, desired constant velocity, maximum bank angles, number of jink segments and jink climb and plane angle. Care must be taken to ensure that these parameters are compatible with one another or excessive gain or loss of altitude will result during the jinking. In testing AJINK, it was usually necessary to adjust the load factor and maximum bank angle to achieve a well-behaved path. It also was found that a relatively high roll rate had to be specified to

compensate for a tendency to lift during a slow roll. Minimum distance from the target at which to stop jinking is an input parameter. It is used to assure sufficient maneuver distance after jinking to perform the attack. If an attack mode is to follow AJINK, the jinking is terminated when this preselected point is reached or when the vector from the aircraft to the aimpoint varies too much over two successive time steps. Otherwise, jinking is terminated when the specified number of jink segments have been completed.

ATTACK

ATTACK defines the flightpath of an aircraft as it performs a conventional dive bombing attack. An attack leg is made up of four sections:

1. Approach to the roll-in point, where maneuvering for roll-in takes place
2. Continued maneuvering prior to roll-in plus aircraft speed adjustment
3. Roll-in, dive, and ordnance release
4. Pullout maneuver.

An option allows jinking to be used during the first two sections to evade enemy fire. Roll-in altitude may be specified or computed in the program. Inputs include the desired dive angle, release altitude and velocity, target coordinates, run-in heading, and pullup *g*-load and pitch angle. So many conditions must be specified that, once again, extreme care must be taken to assure that they are compatible. This includes making hand calculations of the approximate roll-in and release point with relation to the target. If these are not carefully chosen, an unrealistic or nonsensical attack profile will result, necessitating adjustments in the parameters and reruns of the program. It is also necessary to know the weight of the ordnance released and aerodynamic drag coefficient multiplier due to ordnance, as well as the changes in upper and lower *g*-limit caused by the release. The aerodynamic drag coefficient multiplier can be calculated as a function of drag indices tabulated in the external stores section of most tactical manuals. The aircraft's performance will be adjusted by these factors for the rest of the flightpath, including pullup just after release.

NOTE: If the conditions are such at the time of entry into the attack mode that it is not possible to reach the roll-in point at about the proper heading, ATTACK will cause the aircraft to fly a large horizontal loop and make a second approach. Eliminating this unexpected maneuver involves adjusting the preceding portions of the flightpath and rerunning the program.

HARDM

Violent evasive maneuvers are added to a flightpath through HARDM. By using this subroutine, a rapid change of bank, pitch, or track angle, Mach number, altitude, or *g*-loading can be accomplished. A string of these maneuvers can be assembled to form (from an enemy gunner's viewpoint) a random evasive path. The rate of change of bank angle and *g*-loading, and the engine throttle setting, are input. These parameters are used to drive the control parameter to a predefined cutoff value; for example, a 90 degree change in track angle. Unfortunately, hard maneuvers are difficult to control and almost always require some trial and error to achieve the combination that will give the desired overall effect.

PROGRAMMING CHANGES

FAIR PASS is aircraft specific; that is, it is designed to handle only one type of aircraft at a time. Programming changes required to use a different type of aircraft involve the replacement of subroutine VCOMP and five block data subroutines. VCOMP is used to compute aircraft position, velocity components, acceleration, and angular orientation as a function of time. Changing the aircraft specified in the model from an F-4 to an A-7 involves replacement of the F-4 subroutines with an A-7 module which consists of nearly 700 source statements.

An AH-1G module, developed by Bell Helicopter Company, was also tested. It was found to produce satisfactory results for conventional fixed-wing maneuvers. However, standard helicopter operations such as a vertical popup or certain low-speed maneuvers could not be simulated. The explanation for this deficiency is that the equations used in VCOMP during the initial development of the helicopter module were kept relatively simple for testing. These equations were accurate for high-speed maneuvers, but suffered at speeds below 60 knots, where several nonlinear factors became predominant. Simulating low-speed flight would have required development of an alternate set of equations. At about the same time that these problems surfaced, it was decided to design a flightpath generator solely for use with rotary-wing aircraft. This model, MCEP (Maneuver Criteria Evaluation Program), makes use of thrust and power curves to design a flightpath consisting of combinations of a variety of standard helicopter maneuvers. As a result of MCEP development and its acceptance as a helicopter flightpath generator, modifications needed to allow simulation of low-speed helicopter maneuvers in FAIR PASS were never made.

SUMMARY

The FAIR PASS flightpath generator was designed to simulate basic fixed-wing conventional flight and dive bombing tactics. For the F-4 and A-7, this was accomplished in a reasonably efficient manner. Once the user gains familiarity with the program, a realistic flightpath can be obtained for a reasonable investment of time and money. The output is detailed and easy to adapt for compatibility with attrition models which require flightpath history as an input. Certain extreme evasive maneuvers, such as a vertical loop or a 360 degree roll, were not attained in tests although repeated attempts were made. It appears that extensive programming changes would be necessary to accommodate rotary-wing, V/STOL (Vertical Short Take-off and Landing), or other high performance aircraft.

FLYGEN

FLYGEN (Aircraft Flightpath Generator Computer Program) was developed to generate three-dimensional flightpaths for fixed-wing aircraft operating in fighter escort or close air support mode. FLYGEN is a well-written, sophisticated flightpath generator for one aircraft. It is general and versatile in all respects. Although the model is written for detailed aircraft performance data input, it works equally well with lesser amounts of performance data. There are very few maneuvers for which FLYGEN cannot generate accurate flight profiles. To enjoy this mix of sophistication and versatility, it is necessary to learn a complicated input scheme and to pay for significant computer execution times.

INPUT DATA

The input data required by FLYGEN fall into three categories:

1. Aircraft descriptive parameters
2. Program control information
3. Flightpath maneuver coding.

Descriptive Parameters

The aircraft descriptive parameters are entered in tabular form rather than the coefficient approach to aerodynamic data representation. Several types of aircraft descriptive parameters are required. The simplest is the physical characteristics of the clean aircraft. External stores information for up to five separate configurations is input as an array. Extensive tables for two different engine thrust conditions, lift coefficients, and clean aircraft drag characteristics also are necessary. In addition to this information, the aircraft aerodynamic limits, i.e., the maximum coefficient of lift as a function of Mach number, the maximum Mach number as a function of altitude, and control variable limits, (maximum rotation rates and accelerations) must be included to complete the aircraft description. Although data preparation for the descriptive parameters of a new aircraft is laborious, such data decks habe been prepared and are available for several operational aircraft.

Program Control Information

Program control information inputs are simple. Either card or magnetic tape must be specified as the input medium. Output time intervals for both hard copy and magnetic tape also are required. The final piece of program control information consists of a list of tolerances for the various maneuver termination conditions.

Maneuver Coding

Input coding for flightpath maneuvers is in a condensed format, containing many details; consequently, a complex learning effort is required before a new operator can feel at ease with the maneuver coding process. Definition of initial conditions for the aircraft flightpath presents no problems. It is the preparation of data for the individual maneuver specifications that requires close attention to details. Each maneuver specification consists of a string of six one-digit numbers plus nine other data parameters. The six one-digit numbers designate the maneuver type and its options while the nine data parameters specify desired maneuver characteristics. FLYGEN has four types of maneuvers. The six digits and nine parameters have different definitions for each of the four types. This complicated input scheme requires extra effort from the program operator, but it does provide FLYGEN with the versatility that is its forte. With the exception of the first type, each is representative of a different control philosophy. The maneuver specifications are, in general, prepared from the point of view of the aircraft pilot.

NOTE: FLYGEN contains a maneuver modification procedure which greatly simplifies any changes made to an existing maneuver string. This feature makes the input process practical when undertaking parametric studies where large numbers of virtually identical maneuver strings must be processed.

The first type of basic maneuver provides a means to alter aircraft thrust and configuration. It is used to change the external stores configuration upon munitions release or to specify a new engine thrust condition such as cutting an afterburner in and out. As many as five ordnance delivery maneuvers may be flown during one mission. Both mass and drag characteristics are changed for each new external stores configuration. There is no limit to the number of times the engine thrust condition may be switched between the two available thrust ranges.

The second type of basic maneuver is one in which the aircraft flies with a specified rate of change in heading and a specified rate of change in dive angle. Principal use of this maneuver is to generate straight flightpath segments by setting specified rates to zero. It can also be used to produce spirals and barrel rolls. Limits on *g*-loading, maximum roll rate, and time can be stipulated. Aircraft roll angle and *g*-loading are then automatically adjusted to achieve the specified rates within these constraints. Maneuver termination can be directed to occur on any of the following nine conditions: time elapsed, specified altitude or change in altitude, specified velocity or change in velocity, specified heading or change in heading, or, specified dive angle or change in dive angle.

FLYGEN's third type of basic maneuver is one in which the aircraft attains a specified *g*-loading within a given time increment and holds this while adjusting the roll angle to make a specified change in attitude. It is designed for hard maneuvers where the *g*-loading characteristics are essentially known. The maneuver can be terminated at the option of the operator on one of four roll conditions once the aircraft approaches the specified attitude (heading and dive angle). Three of these options are used to cause the aircraft to roll its wings level at such time that the specified heading, specified dive angle, or both are exactly attained. In the case of a string of hard maneuvers where the angular rate should be maintained from one maneuver segment to the next, the fourth option makes no attempt to alter the natural roll rates as control passes between segments.

The fourth type is one in which the aircraft rolls to a specified roll angle and then attains a specified *g*-loading within a given time increment. Both the roll angle and the load are maintained until a specified termination condition is satisfied. The maneuver can be concluded by the same nine conditions as in the second maneuver type. This fourth maneuver is used mainly to perform controlled rolls and breakaway actions. Under most circumstances the roll rate is bled off at the desired roll angle. For strings of roll maneuvers, however, an option is available in which the roll rates are not bled to zero. This allows a steady roll rate throughout a multiple roll maneuver.

It should be noted that FLYGEN always rolls the aircraft in the direction which necessitates the least angular displacement. Consequently, maneuvers which require rolls in excess of 180 degrees must be performed as a series of maneuvers of the fourth basic type. It is in this situation that the option to sustain the roll rate between maneuver segments is best utilized.

The operator has speed control in the second, third, and fourth maneuver types. This involves thrust and speed brake settings. Only the Mach number versus altitude limits can invalidate operator instructions. If a Mach number limit is exceeded, specified speed control is countermanded in an effort to reduce airspeed. The operator has the latitude to directly

set the thrust or speed brake setting, or direct that they remain at their original settings throughout the segment. It can be specified that thrust and speed brake settings be adjusted to maintain either the airspeed or Mach number held at the beginning of the segment. Finally, the operator may stipulate that these settings be adjusted to attempt a specified airspeed or Mach number.

OUTPUT DATA

FLYGEN generates three output lists. The first is the usual hard copy; the second, an optional hard copy with additional information; and the third, a magnetic tape with information for attrition modeling. The printed output begins with a summary of the aircraft descriptive parameters. It is followed by a list of the maneuver string inputs. Subsequent to these two summaries is the time history of the flightpath simulation. Output data consist of the following:

1. time, sec
2. position, m
3. velocity and its components, m/sec
4. attitude, deg
5. *g*-loading
6. thrust and speed brake settings
7. lift, drag, and thrust, KN
8. message array.

The message array contains five flags which signal when a corresponding limit has been encountered. Once the time history is completed, a summary of the maneuvers actually flown is produced. This is basically a list of time, position, airspeed, attitude, and *g*-loading at the end of the segment.

The optional hard copy contains a time history of other variables associated with the simulation. While the primary output lists quantities with respect to the inertial reference system, this output consists of much the same information but lists it with respect to the body axis system. The quantities include velocity vector components, acceleration vector components, angular velocity components, time derivatives of heading, dive, and roll angles, the sideslip angle, aircraft side load, coefficients of lift and drag, and the same message array as previously described.

The magnetic tape output listing was designed to be used in conjunction with AA attrition simulation models. It contains more than enough information concerning the aircraft flight profile for current attrition models. Items listed on the tape are:

1. time, sec
2. position, m
3. velocity and its components, m/sec
4. acceleration components, m/sec^2
5. *g*-loading
6. attitude, deg.

MATHEMATICAL MODEL

The mathematical approach to FLYGEN is rigorous. The kinematic derivations are based upon a point mass with six degrees of freedom over a flat earth. Unlike most flightpath generators, both the first and second order terms are included in the six equations of motion. These equations are solved simultaneously and integrated in order that velocity and angular rate components may be updated. Generally, the aircraft is controlled by means of the thrust and speed brake parameters and by directly controlling angular velocity components. In all cases, the roll rate is used to control the roll angle, pitch rate is used for control of g-loading, and yaw rate is adjusted to minimize sideslip. Therefore, all turns are coordinated.

The sign conventions which have been adopted for FLYGEN are based on a conventional right-hand axis system. As referenced to an axis system which moves with the aircraft center of gravity but remains parallel to the inertial axis system, the aircraft nose faces in the positive X direction, the left wing and the positive Y-axis coincide, and the Z-axis is positive upward. Roll, dive and heading angles are defined as right-handed rotations about the X, Y, and Z axes, respectively. Dive angle should receive particular attention. As defined, a nose downward rotation is positive and a nose upward rotation negative. All inputs and printed outputs reference this dive angle; however, the magnetic tape output refers to the pitch angle (nose upward, positive) which conforms to sign conventions of P001.

Two other points concerning the math model should be noted. First, aircraft mass does not decrease as a result of fuel consumption. It remains constant except for the abrupt changes which occur upon ordnance delivery. Secondly, a chaining option is available at the end of the input procedure whereby in-flight changes in aerodynamic or performance data may be made at the end of the maneuver string. This option could allow FLYGEN to be used for some new generation, nonconventional aircraft.

MODEL ASSUMPTIONS

It is necessary to become reasonably familiar with the practical side of FLYGEN. This is not to imply that further surprises will not occur later. It is instead a description of initial learning experiences. One of the first difficulties encountered involved the oscillation of the aircraft attitude about the specified conditions before the maneuver segment terminated. This produced a very realistic flightpath most of the time. There were occasions, however, when oscillations continued beyond a period of believability. This situation occurred most often when a dual angle termination condition had been specified. Once recognized, it was a simple matter to increase the tolerances of the termination angles or to change to a less demanding termination condition. The latter was more frequently used.

It was noticed that some maneuvers which specified wings-level terminations on either heading or dive angle took many seconds to execute. From the printed output listing, it appeared that the aircraft would approach the proper attitude to within approximately twice the termination tolerance and then oscillate for several seconds. To accelerate the maneuver, the first maneuver specification was changed to eliminate the unroll option. It was then followed by a fourth basic type segment which specified a zero roll angle and a quick termination time.

The only problem which was not readily solved occurred when a maneuver was accidently allowed to continue until the time surpassed the segment default limit. Immediately upon initiation of the next segment, execution was halted due to the internal generation of an infinite number.

SUMMARY

In conclusion, FLYGEN is a sophisticated flightpath generator which can simulate nearly all aircraft maneuvers in a realistic manner. It is adaptable to all present-day fixed-wing and some nonconventional aircraft. The rather substantial execution times and complex input scheme are two factors which must be weighed against this model's versatility.

BLUE MAX

BLUE MAX (Variable Airspeed Flightpath Generator Computer Program) was developed to generate three-dimensional flightpaths for fixed-wing aircraft. BLUE MAX is a straightforward, well-written flightpath generator for one aircraft. It is a short, simple program which lends itself best to ground attack mission modeling. The model contains performance data for five aircraft (A-7, A-10, MIA, F-4 and FOX) and space for a sixth. Data for FOX show it to be representative of a high performance, experimental aircraft of the 1970s. Having the performance characteristics stored within the program simplifies input data requirements. Input data consist of an aircraft identifier, munition release (attack) conditions, desired trajectory parameters, and maneuver segment control information. The trajectory parameters are prepared from the point of view of an observer outside the aircraft. Desired heading, airspeed, altitude, and pitch are the only performance values specified for each maneuver segment.

INPUT DATA

There are three input parameters which control maneuver segments[6]. The first is a maneuver code. The model contains five segment types: navigation, base leg, attack, pull-out, and recovery. Each has a unique set of performance limits which include: maximum roll rate and angle, maximum throttle rate, and maximum *g*-rate and loading. All aircraft maneuvers, whether simple straight line flight or complex strings of break techniques, must be performed within the limitations of one of these segment types.

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[6]An updated version of BLUE MAX has been prepared recently which includes two additional types of maneuver segments. These changes are reported to yield a considerable amount of versatility to the basic simulation model by providing maneuver segments which are tailored to escape maneuver simulation and to point-in-space navigation. Further information can be obtained from the Assistant Chief of Staff, Studies and Analysis, Headquarters United States Air Force.

The second input control parameter is a time limit for the segment while the third is a heading flag. Both inputs involve segment termination conditions. There are three ways to terminate. First, the model progresses to the next segment leg at the designated time limit. Second, it continues to the next segment when the aircraft reaches the lead point for rollout on the specified heading if the flag has been set. The lead point is defined as that position along the trajectory at which the aircraft should begin terminating a maneuver, e.g., that point at the end of a tight turn with an automobile when the front wheels are allowed to begin straightening out. Third, the segment ends when the aircraft arrives at the lead point for level off on the commanded altitude. The third condition applies only during a change in altitude when specified pitch is not zero. It does not apply during the attack segment. In that case, the segment ends on the release altitude and not the lead point for level off.

Because BLUE MAX is written primarily for the ground attack mission, it has certain characteristics which are peculiar to that phase of the flightpath. The aircraft flies maneuvers as directed by the trajectory parameters until the munition release segment is completed. The prerelease portion of the flightpath is then translated such that the proper release conditions are obtained for a target positioned at the origin. In addition to translation in the horizontal plane, the flightpath is also adjusted in the vertical plane. This is an iterative process which can produce surprising results in some cases, one of which will be described later. Because a portion of the flightpath is translated to obtain the correct release conditions, only one attack segment is permitted per flightpath. There is no limit to the number of repetitions for other segment types.

Aircraft control during maneuvers is in the form of rate control over the *g*-loading, roll, and throttle parameters. Roll rate is adjusted as a function of the difference between the specified heading and the aircraft heading at time *t* corrected by the heading rate. Likewise, the throttle rate is adjusted as a function of the difference between commanded velocity and the velocity at time *t* corrected by the rate of change of velocity. *G*-rate is adjusted in much the same manner but with a special provision for segments with a specified pitch of 0 degrees. This also occurs as the aircraft is leveling off after passing a lead point. In this case, *g*-rate is a function of the difference between the commanded altitude and the aircraft altitude at time *t* corrected by the rate of change of altitude. For climbing and diving flight, *g*-rate is a function of the difference between commanded pitch and aircraft pitch at time *t* corrected by pitch rate.

Limits for *g*-loading roll, and throttle parameters as well as the *g*-rate, roll rate, and throttle rate are defined for each maneuver segment type. Rate algorithms (described above) adjust the control rate to its maximum until the control parameter reaches its own limit. Throughout a given maneuver, the control parameter remains at its maximum value until the commanded flight conditions are approached. The control rates and parameters then move away from their respective limits and return to the values necessary to maintain the commanded flight conditions. Such a control scheme produces a flightpath with nearly constant radius of curvature maneuvers. During the last seconds of each maneuver, the commanded conditions are approached asymptotically. No flightpath oscillations occur near maneuver termination points.

OUTPUT DATA

Output information of BLUE MAX is more than adequate for attrition modeling. However, it is not in a form which can readily be prepared for input to the standard AA attrition model P001. Unit conversions, velocity component calculations, and sign convention adjustment are necessary to adapt the hard copy output of this flightpath generator for P001 input. The output parameter list consists of the following:

1. time, sec
2. position, ft
3. velocity, knots
4. direction, deg
5. attitude, deg
6. throttle setting, loading, tracking time, and slant range to target.

The sign conventions adopted in this model are based on a right-hand coordinate system. The earth or inertial axes are oriented with the X-axis pointed north; the Y-axis west; and the Z-axis positive upward. Pitch and roll are conventionally defined with nose-up pitch and right wing down roll considered positive rotations. Heading is defined as a standard compass heading increasing clockwise from the north.

In the mathematical derivations of BLUE MAX, the aircraft is treated as a point mass with five degrees of freedom. No provisions are included for yaw. The equations are written for flight over a flat earth in the wind axes coordinate system. Resulting accelerations are then transformed to the inertial reference axes and integrated by a fourth order Runge-Kutta integration scheme.

The system of aerodynamic forces employed in BLUE MAX is conventional except for the treatment of thrust. The thrust vector is assumed to point at an angle equal to the angle of attack with respect to the relative wind vector. This assumption has the effect of maintaining a constant angle between the thrust vector and the aircraft centerline even during high-*g* maneuvers. Other models have traditionally assumed that the thrust vector was aligned with the relative wind vector. Neither approach is exact, but the BLUE MAX treatment is much closer to real life during hard maneuvers.

MODEL ASSUMPTIONS

A few other assumptions included within the model should be noted. Aircraft weight is assumed to remain constant throughout a mission. Munition drag increment coefficients are included in drag calculations. At munition release, however, there is no change in aircraft mass or drag. Provisions are made for speed brakes if the individual aircraft is so equipped. The operator does not have direct control at any time over throttle or speed brake settings, however; the speed brake is used only during the attack segment.

The control scheme produces realistic results and works well for the approach and attack sections of a ground attack mission, although there is some question about the accuracy of the resultant trajectory during hard maneuvers. One such case occurs when a rapid reduction in pitch is required; in actual operation, the aircraft would roll onto its back to use its lift vector as a driving force. However, BLUE MAX has roll angle limits less than 90 degrees for all segment types except the attack. This means the aircraft cannot roll far enough to use its lift vector for pitch reduction and therefore must rely on gravity as a driving force.

Besides the frustrations associated with rapid maneuvers, a few other surprises were encountered. As described previously, an iterative process is used to translate the flightpath for a ground attack mission. No output is generated until the translation process has been completed. If during this procedure, either the altitude or velocity limits are violated, the entire run is terminated with a nondescriptive error message. It is a simple matter to maintain the airspeed within limits, but altitude limits present a different problem. The algorithm which translates the premunition release flightpath segments in the vertical plane adjust the commanded altitudes as a function of the difference between the commanded and the actual tracking times. This difference is multiplied by the vertical velocity and an empirical weighting factor before being added to the commanded altitudes of the previous iteration. If a situation exists where there is a great difference between the commanded and actual tracking times with a steep dive angle and a high approach velocity, it is likely that altitude adjustments involve many hundreds of feet. Such a translation can result in several abrupt terminations without the help of diagnostic messages before the causative factor is recognized and eliminated by trial and error.

A second surprise occurred when a steep popup maneuver to a specified altitude was attempted. The climb segment terminated on the lead point for level off at the command altitude. Aircraft altitude at that time was considerably below the command altitude. When an additional segment was included to bring the flightpath to the desired altitude, the aircraft gradually rolled out and leveled off. This destroyed the popup maneuver effect. A tentative solution was reached by increasing the command altitude beyond that actually desired. Several attempts were required to adjust the climb segment termination point to the desired altitude.

The command heading input parameter is handled in a slightly different manner than was first expected. This was first noticed when a command heading of -270 degrees was input for one flightpath segment and 45 degrees for the next. Instead of rolling left and performing a 45 degree left-hand turn as was anticipated, the aircraft rolled right and executed a right-hand turn for 315 degrees. Such a heading convention presents no particular problems if the operator is aware that it exists. Indeed, it provides a convenient method to perform multiple loop spirals.

One additional comment should be made concerning the use of BLUE MAX for a fighter escort mission. It is not really intended to be used for missions other than ground attack. The general approach to both the control scheme and the maneuver limits was built around the smooth flight of ground attack missions. The quick maneuvers of air combat emerge from BLUE MAX as a string of segments which are more gentle and blurred together than in the actual combat situation. In fact, if no attack segment is included in the list of maneuvers, BLUE MAX produces no output list. To examine the results of this generator for a fighter escort mission, it was necessary to change one program source statement.

SUMMARY

Overall, BLUE MAX is a straightforward, cleverly written, manageable, and efficient flightpath generator. It produces reasonable results with a minimum of input preparation. A nonprogrammer wishing to generate a conventional ground attack profile should experience few problems once the flightpath translation characteristics of the model are understood. An operator with a FORTRAN background can truly appreciate the simplicity of the model. Most of the problems which were encountered can easily be remedied by changing control parameter limits. These limits and the aircraft performance characteristics can be identified readily in the first few lines of the program. BLUE MAX is good for attrition studies which require conventional ground attack flight profiles.

MCEP

MCEP (Maneuver Criteria Evaluation Program) is a digital computer program developed as an aid in the determination of maneuver requirements for helicopter design specifications[7]. It is a well-written flightpath generator for one conventional or winged single-main-rotor helicopter. MCEP provides the capability to build up a mission from 15 various types of maneuvers. These maneuvers range in complexity from a basic straight line cruise segment to an involved dive/rolling-pullout attack maneuver. Each type provides a realistic simulation of actual helicopter trajectory when used on an individual basis. However, the simulation is less accurate during the transition between maneuvers when two or more segments are executed together in a mission sequence due to the inclusion of a steady-state straight-and-level flight attitude at the beginning and end of each maneuver. Consequently, the program lends itself best to straightforward ground attack missions and other nonviolent maneuver strings.

INPUT DATA

Input data necessary to execute the program fall into three categories:

1. Helicopter descriptive parameters
2. Program control information
3. Maneuver specifications.

The program control data and the maneuver specification data are straightforward and easily prepared. Program control information consists of integration step size, output time interval, and several parameters which control performance histograms in the output listing. Maneuver specification data vary for each of the 15 segment types. Since several maneuver types are constrained to one type of motion, specification data typically consist of one or two descriptors which designate desired flight conditions at the end of the segment. In addition, such information as load factor, velocity, direction of turn, and urgency of maneuver index are required. These specifications are generally prepared from the standpoint of an observer other than the helicopter pilot.

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[7]U. S. Army Air Mobility Research and Development Laboratory. *Maneuver Criteria Evaluation Program*, by T. L. Wood, D. G. Brigman, Bell Helicopter Company. Fort Eustis, VA., SAVDL-EU, May 1974. 132 pp. (Publication UNCLASSIFIED.)

Data containing helicopter descriptive parameters are compact and very efficient. Only nine data cards are required to characterize the helicopter. In order to maintain a simplified computational procedure, the many curves necessary to portray the performance of a rotary-wing aircraft are defined by means of parametric equations. The coefficients of these equations occupy a sizable portion of the data. These coefficients pertain mainly to rotor power and thrust relationships, to wing aerodynamics, and to a fuselage angle of attack correlation. The remainder is comprised of control response time constants, rate limits, fuselage drag characteristics, wing geometry parameters, gross weight, and initial conditions for the flightpath.

Some parametric performance equations are presented in a recognizable form while others are empirical in nature and tend to best fit performance curves of small helicopters such as the AH-1G. Large helicopters can be accommodated by substituting higher order parametric performance equations into the program. Because of the unique nature of certain performance equations, the parametric coefficient data may be difficult to obtain except by means of regression analysis techniques. A prospective MCEP user who is not familiar with helicopter performance terminology may find it necessary to consult with persons knowledgeable in the field before obtaining satisfactory flight performance simulations.

FLIGHT PROFILES

MCEP contains a sophisticated means for generating flight control commands. It utilizes a mix of program feedback values and operator control inputs to produce flight control parameters. Four such parameters are used to control the helicopter flight profile: velocity pitch, velocity roll, normal load factor, and rate of change of velocity. The program operator, in general, specifies a desired velocity, a desired load factor, and an angular rate proportionality constant for each maneuver. The program adjusts the velocity-change parameter accordingly through the rate and magnitude of power supplied from the engine. MCEP generates the two angular control parameters by estimating the load factor as a function of time to produce the desired trajectory and load factor. The pitch and roll parameters thus determined are varied such that a trace of the angular acceleration history matches the shape of an exponential control function. The time period over which the exponential change in angular rate occurs is adjusted by the program logic to maintain the rate below a specified maximum. This maximum is defined through the use of the previously defined angular rate proportionality constant.

The rate algorithms described above adjust the control rate to its maximum until the control parameter reaches its own limit. Throughout a given maneuver, the control parameter remains at its maximum value until commanded flight conditions are approached. Control rates and parameters then move away from their respective limits and return to the values necessary to maintain the command conditions. Such a scheme produces a flightpath with nearly constant radius-of-curvature maneuvers. During the last seconds of each maneuver, the commanded conditions are approached asymptotically. No flightpath oscillations occur near the termination point. The trajectories that result from such a control philosophy are a reasonable approximation of actual helicopter flight profiles, especially for those missions flown in a low-threat environment.

The simulation of mission profiles requires that each one be defined as a series of individual maneuvers. Each mission profile can consist of any number of maneuver segments. The mission is specified by ordering the required maneuver specification input data cards in the sequence of their occurrence in the profile. Each segment is completed before the program will consider the next maneuver. The simulation terminates only when it exhausts the list of input maneuver data cards.

Obviously there are not 15 basic motions indigenous to helicopters. Seven MCEP maneuvers can be described as basic:

1. Straight and level cruise
2. Acceleration/deceleration at constant altitude
3. Climb/descent at constant airspeed
4. Flat turn at constant airspeed
5. Sideward acceleration/deceleration
6. Pedal turn at hover
7. Collective popup at constant attitude and low airspeed.

The other eight are canned routines which occur frequently in attack helicopter missions or in design maneuverability specifications. They include:

1. Pullup/pushover at a desired load factor
2. Auto turn at constant airspeed and altitude
3. Return to target at constant airspeed
4. Dive/rolling pullout
5. Climbing/descending turn at constant airspeed
6. Sideward acceleration/pedal turn into the wind
7. Orbit at constant airspeed
8. Climbing return to target.

It should be noted that the side conditions placed on the basic MCEP maneuvers are limiting in some circumstances. The constant airspeed constraint in the climb/descent maneuver is an example. It is frequently desirable to execute an accelerating dive as an escape maneuver in threat engagement scenarios. Obviously, the climb/descent will provide a dive in the simulation, but the helicopter will descend at a constant velocity. This effect is hardly noticeable for descents from low altitudes; however, the realism of the simulation suffers for escape maneuver descents from medium or high altitudes. Side conditions most often become constraints during violent mission profiles; they rarely interfere with missions which take place in an unhurried environment.

MCEP has one other trait that makes realistic simulation of violent maneuver strings difficult. Each maneuver begins and ends with the aircraft in a flat-and-level attitude in steady-state flight. Only at the very end of an evasive maneuver string does a helicopter approach this condition in a true combat environment. Likewise, one would not normally expect to find two flat-and-level steady-state segments in the middle of a turn/dive/turn escape maneuver simulation.

Aircraft survivability assessment studies involving small arms threats regularly require that the aircraft utilize its full range of performance capabilities to avoid or escape the immediate threat area. In the case of helicopters, this means fully powered turning dives to the relative safety of nap-of-the-earth flight with its inherent terrain masking advantages. Both previously described MCEP maneuver limitations come into play when this type of escape simulation is attempted. As a result, an MCEP-generated flight profile is not always sufficiently realistic. Because this is the best flightpath generator currently available for helicopters, the operator is either forced to settle for something which does not describe the actual situation, or many man-hours must be spent modifying data so that they will resemble the actual case. Such modifications are often less than satisfactory; their accuracy, questionable; and their cost, prohibitive.

OUTPUT DATA

MCEP generates two types of hard copy output. The first is a time history of the flightpath simulation; the second, a series of helicopter performance histograms. The usual printed output for each maneuver begins with a listing of the helicopter descriptive parameters and the maneuver input specifications. It is followed by a detailed listing of the flightpath simulation parameters as they vary with time. Flightpath output data include:

1. time, sec
2. position, ft
3. velocity rotation angles, deg
4. fuselage angle of attack and pitch angle, deg
5. load factor, airspeed, knots
6. vertical velocity, ft/sec
7. linear acceleration, ft/sec^2
8. velocity angular rates, deg/sec
9. power setting, and total horsepower.

The summary section that follows the time history is comprised of a comparison between the entry and exit conditions for the maneuver segment. Time history information is more than adequate for attrition modeling. It is not in a form which can readily be prepared for input to the AA attrition model P001, however. Unit conversions, velocity component calculations, and sign convention adjustments are necessary to adapt the hard copy output of this generator for P001 input.

The second type of output listing is a series of helicopter performance histograms. This form is optional and may be eliminated by assigning appropriate values to histogram control parameters in the input data list. Histograms are available for power, altitude, airspeed, and load factor.

MATHEMATICAL MODEL

The MCEP mathematical model is based upon energy method derivations[8]. The energy state of the helicopter is calculated in terms of its required power as a function of the flight conditions at a given instant in time. The difference between the power required and the power supplied by the engine is then used to increase the helicopter potential energy (altitude), its kinetic energy (velocity), or to change its direction of flight as required by flight control commands. Since energy methods cannot determine fuselage angle of attack, an empirical equation is used to predict helicopter orientation for the wing aerodynamic calculations. This clever combination of energy and empirical techniques greatly simplifies the problem of defining the flight dynamics of rotary-wing aircraft.

It should be noted that the mathematical model assumes the mass of the helicopter remains constant throughout a mission. This assumption has the effect of streamlining the computational scheme. The math model is further simplified by neglecting density and velocity of sound variations with altitude. This is a reasonable assumption since helicopters do not typically traverse great expanses of altitude during a mission.

As with most flightpath generators, MCEP operates principally with both wind axes and earth (inertial) axes coordinate systems. The earth axes are defined as a right-hand system such that when the positive X-axis is pointed north, the positive Y-axis is pointed east, and the positive Z-axis is pointed downward. Likewise, the wind axes system is defined similarly. Angles and angular rates referenced in the input and output listings are defined as customary aerodynamic rotations of velocity yaw, pitch, and roll with respective rotations of nose right, nose up, and right-wing-down being considered positive angular displacements. It should be noted that the angle of attack parameter applies to the relative angle between the aircraft velocity vector and the local horizontal plane (e.g., floor) of the fuselage. The other fuselage attitude angle, fuselage pitch angle, refers to the included angle between the fuselage nose vector and the earth horizontal plane. This leads to one final point: provisions for fuselage body yaw (sideslip) have not been included in the mathematical model except in the two maneuvers which generate sideward motion.

SUMMARY

Even though MCEP is not optimally suited for aircraft survivability applications, it is the best available flightpath generator for helicopter attrition modeling. Program input data are somewhat detailed yet brief enough to be manageable. The 15 types of maneuvers allow all the basic helicopter flight motions and provide a means to readily handle frequently encountered maneuver strings. MCEP simulation is mathematically accurate and efficient. Output data are sufficiently detailed to ensure operator confidence in the simulation, and adequate, with some modifications, for use with traditional attrition models. While the best simulations are obtained for nonviolent maneuver strings, acceptable results can be generated for hard maneuvering flight sequences by judicious flightpath editing. Finally, the MCEP control scheme provides ample power to regulate flightpath simulation so that the resulting profile adequately resembles the desired aircraft trajectory. This trait provides a valuable time savings by eliminating the numerous simulation repetitions normally required to shape the general form of an aircraft flight profile.

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[8] U. S. Army Air Mobility Research and Development Laboratory. *An Energy Method for Prediction of Helicopter Maneuverability*, by T. L. Wood and C. L. Livingston, Bell Helicopter Company. Fort Eustis, VA., USAAMRDL, December 1971. 101 pp. (BHC Report 299-099-557, publication UNCLASSIFIED.)

SUMMARY

As indicated by the four flightpath generators, the state-of-the-art for this type of digital computer program is not sufficiently advanced to allow impromptu creation of any flightpath simulation, especially a complex mission profile. Currently used flightpath generators typically require a significant amount of preparation for both the aircraft descriptive input data and maneuver specification data. Even after input data are prepared and the first flight simulations completed, an extensive period of maneuver data modification and reiteration is normally required to attain an acceptable flight profile. This is not so much due to the maneuver specification input schemes as to the practical problem of controlling the solution of five or more simultaneous differential equations of motion. The control scheme utilized by each program essentially determines the extent to which the simulation may be regulated by the program operator. Those programs which employ extensive internal control logic typically do not require much input data, but neither do they provide much operator control. Flightpaths from such programs appear nearly identical to each other regardless of efforts to change their appearance. Conversely, those programs which place the burden of simulation control on the operator typically utilize complex input schemes, but impose few limits on the variety of flightpath forms which they can produce. Such an approach yields, in addition to versatility, a simulation program that generates predictable profiles. Consequently, a finished flightpath is obtained in an efficient manner without numerous expensive attempts to mold the flight profile into a desired form. There is a definite tradeoff between the time required to obtain an acceptable flight profile and the degree of complexity or exactness involved in the desired simulation.

The four flightpath generators reviewed in this report cover a wide range of usability, complexity, and versatility. BLUE MAX is a short, easy to use flightpath generator designed for simulation of ground attack missions by fixed-wing aircraft. Initial familiarization with the workings of the program requires no more than a few hours. Input data requirements are minimal. No aircraft data input is necessary if one of the five predefined aircraft is utilized in the simulation. Most of the flightpath control functions are integral parts of the program, so maneuver control parameters are limited to basics such as heading, altitude, velocity, and tracking information. The flight profiles produced by BLUE MAX are quite acceptable for generalized straightforward ground attack missions.

FAIR PASS is designed primarily for simulating ground attack missions of fixed-wing aircraft; however, the program also is capable of handling air-to-air scenarios and rotary-wing aircraft. It is somewhat more complex than BLUE MAX. Acclimation to the program's operation may require several days. Since the basic aircraft performance data is contained within the program in the form of block data, only flightpath maneuvers need to be specified in the input data. The maneuver specification scheme is simplified due to the placement of the simulation control logic within the program. Here again, as in BLUE MAX, the predicatability of the output flight profile is compromised in favor of predetermined control logic and simplified input requirements. Flightpaths generated by FAIR PASS are very realistic for most ground attack missions; however, the simulations are less reliable for air-to-air engagements or other scenarios which require a series of hard maneuvers.

FLYGEN is the most versatile flightpath generator for fixed-wing aircraft. It is a sophisticated program which can simulate nearly all aircraft maneuvers in a realistic manner. As would be suspected, the expanded capabilities of this program are made possible by an increased initial workload on the program operator. A few days of intensive study are required to familiarize a new user with the detailed aircraft description and maneuver specification schemes. Once mastered, however, FLYGEN produces the most predictable, hence least costly, simulations of all current flightpath generators. This is largely due to the program's advanced control scheme which allows the operator to regulate a wide range of control parameters in maneuver specification data.

MCEP cannot be compared directly with the other flightpath generators in this report since it is designed solely for rotary-wing aircraft. The program is simple, efficient, and relatively easy to use. Although the helicopter performance data are somewhat complicated for a novice to prepare, the maneuver input scheme is straightforward and can be learned in a few hours. One of MCEP's major advantages is that it does not require complex or lengthy mission input preparations but yet produces flight simulations that can be readily controlled. The flight profiles so generated are of sufficient accuracy for all but the most demanding helicopter survivability studies.

The four flightpath generators reviewed in this report are but a few of the flight profile simulators in current use. However, these are the programs most frequently utilized by the aircraft survivability community. Each model will produce simulations which are quite adequate for the current state-of-the-art in aircraft attrition studies. Furthermore, these same programs could conceivably continue to fulfill this need for conventional aircraft in the future. However, near-future advances in aircraft technology such as nonconventional concepts in thrust and lift generation, drag reduction, or variable cycle engines undoubtedly will require modification or replacement of the present generation aircraft simulations. Hopefully, at that time, the efficiency of the flightpath generation process will be improved by eliminating the need for repetitive simulation runs. This could be accomplished by developing a simulation program with a control scheme which allows interation between the program operator and the program on a real real time basis. Ideally, the flightpath generator would be integrated with the attrition model such that the flight profile of the aircraft would interact with AA threats contained in the attrition model.

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This report describes the findings of an investigative analysis of four flightpath generation computer models. The four models (FAIR PASS, FLYGEN, BLUE MAX and MCEP) are commonly used in the aircraft survivability/vulnerability community. The

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